TWO AIRCRAFT HEAD-UP TRAFFIC SURVEILLANCE SYMBOLOGY ISSUES: RANGE FILTER AND INBOARD FIELD-OF-VIEW SYMBOLOGY

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ABSTRACT

The purpose of the eXternal Visibility System (XVS) effort for NASA's High-Speed Research Program was to determine and to provide required pilot visual information for a High Speed Civil Transport vehicle concept to allow safe and efficient operation in the absence of forward windows. The objective of this preliminary experiment conducted at NASA Langley Research Center was to investigate two head-up surveillance symbology (HUSS) display issues. The first issue was concerned with the benefits of adding a range filter to the current HUSS concept. A range filter limits the amount of traffic symbols displayed head-up by setting a range boundary (e.g. 7-nmi) around the ownship. The second issue was concerned with the need to incorporate HUSS in the inboard field-of-view (IFOV) display of the XVS concept. The hypothesis tested was that adding a range filter to the XVS display and HUSS to the IFOV display would enhance the pilot's effectiveness of traffic surveillance tasks. Using a high-resolution graphics flight simulator, each of three pilots flew departure and arrival scenarios under visual meteorological conditions. The pilots' main tasks, while managing flight path, were to detect and assess potential airborne traffic hazards and to maintain overall situation awareness. Upon completing all the runs, each pilot completed a subjective questionnaire. Results showed that having both the HUSS on the IFOV and the range filter on each of the XVS displays enhanced the effectiveness of the XVS surveillance display concept. This configuration had the least head down time and the lowest mental workload. Combining both features gave the best target detection, the earliest threat recognition, and enabled the pilots to create a better strategy for evasive action when it became necessary.

INTRODUCTION

An experiment entitled head-up surveillance symbology (HUSS) was held in January 2000. This experiment was a portion of the eXternal Visibility System (XVS) effort under the High-Speed Research Program. The XVS effort focused on the cockpit display issues of the High Speed Civil Transport (HSCT). The HSCT was a conceptual vehicle developed as a joint effort between NASA and several industry partners. It was intended to develop the necessary technologies for the next generation supersonic civil transports. The XVS effort was focused on a concept to provide forward visibility in the absence of forward windows for pilots of the HSCT. This absence of forward windows made feasible the decision to not droop the nose of the HSCT, providing considerable savings in weight, cost, and mission constraints.

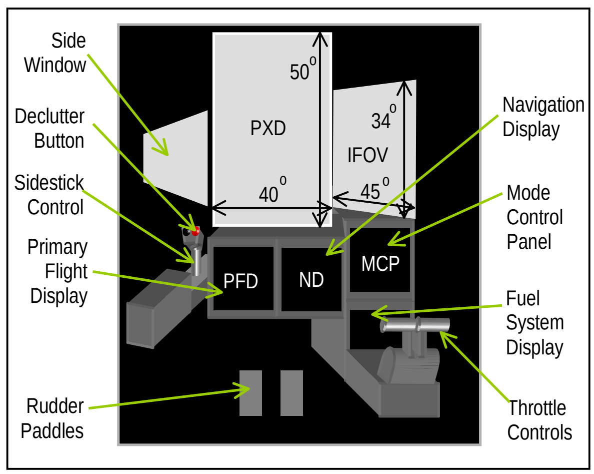

Figure 1. High Speed Civil Transport's External Visibility System

This experiment was held to investigate two HUSS display issues. The first issue was concerned with the benefits of adding a range filter to the current HUSS concept. A range filter limits the amount of traffic symbols displayed head-up by setting a range boundary around the ownship, outside of which, no non-threatening traffic symbol is displayed. The second issue was about the need to incorporate HUSS to the head-up Inboard Field of View (IFOV) display. The addition of an IFOV display was the result of the study by Dr. James R. Comstock (as yet undocumented). This study investigated the addition of a conformal IFOV display to the HSCT's cockpit, thereby extending the pilot's visual Field-of-View when only one pilot is flying head-up. This display presents to the pilot that portion of the forward view that the copilot views through his side window. Figure 1 is a schematic of the pilot's side of the XVS concept. The hypothesis tested was that adding a range filter to the XVS display and HUSS to the IFOV display would enhance the pilot's effectiveness in traffic surveillance tasks.

HUSS on Primary XVS Display

Prior to the addition of the IFOV display, Kramer and Norman (ref. 1) of NASA Langley Research Center (LaRC) examined the benefits of providing HUSS on the HSCT's head-up Primary XVS Display (PXD). Their results indicated that providing HUSS on the PXD improved the pilot's ability to detect and assess potential airborne traffic hazards.

HUSS Definition

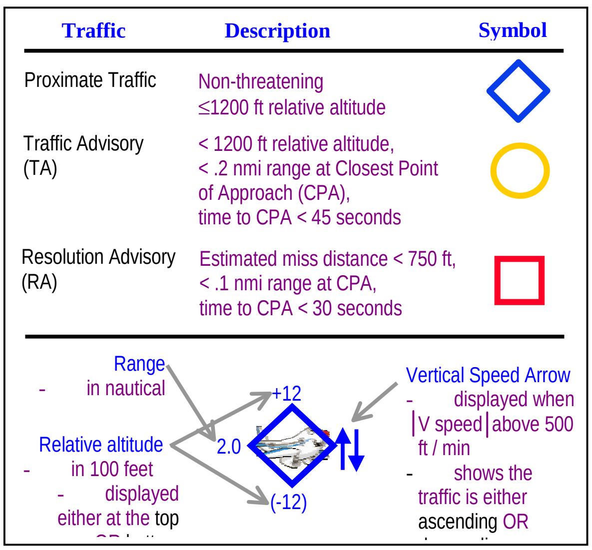

Figure 2. Head-up surveillance symbology (HUSS) definition.

The HUSS definition uses the standard TCAS symbology set except that the symbols are modified to a hollow design to avoid occluding critical information on the display. HUSS is generated when the ownship encounters traffic conditions that fall within one of the following alert categories: the proximate traffic alert, traffic advisory (TA) alert, and resolution advisory (RA) alert. Figure 2 provides a detailed definition of the various traffic alert categories. Like the head-down ND, the same HUSS definition is used to represent traffic of different surveillance sensor types. The HUSS also grows in size as the traffic enters a 5-nmi boundary within the ownship. However, the size of the alphanumeric text remains constant at all times. Furthermore, the size of the range filter is 7 nmi[1]. Aircraft generating TA and RA alerts are considered threatening traffic and hence are presented to the pilot whenever they occur.

HUSS on IFOV display?

Dr. Comstock's IFOV display work identified the potential need to incorporate the HUSS onto the IFOV display. The benefit of display symbology on the IFOV must be carefully weighed against the potential for creating clutter on that display. The presence of clutter is particularly objectionable in a high traffic situation. Therefore, any candidate for enhancing traffic detection that involves additional symbology should ensure the control of clutter.

Limiting the Traffic Display Range to Reduce Clutter

Merwin in his traffic symbology study for XVS (ref. 2) suggests several schemes to reduce traffic symbology clutter. Among them is the range filter concept. His limited study appeared to indicate that the range filter was valuable with respect to traffic detection and situation awareness.

Much research has only touched upon the issue of traffic display range. In J. W. Andrew's 1996 study of a head-down TCAS in the Long Ranger Helicopter (ref. 3), he mentioned that pilots preferred to limit the amount of traffic symbology by a variable range display. He concluded that for helicopters, the display of traffic beyond 3 nmi in range was seldom useful because it decreased display readability and increased clutter problems for the nearby traffic that was usually of most interest.

Dudfield (ref. 4) pointed out that the subject pilots in her study were typically satisfied with a surveillance display range of 5 km (2.7 nmi) for providing sufficient situational awareness and minimizing display clutter. However, optimum range was felt to be dependent on the ground speed.

E. E. Geiselman and R. K. Osgood in their 1995 Helmet-Mounted Display (HMD) work for military jet fighters (ref. 5) applied a 5 nmi target range to the HMD. This 5-mile threshold target range was larger than the 5-km (2.7 nmi) range suggested by Dudfield (ref. 4). From these studies (ref. 3-5), one can infer that

[1] A summary of the pre-experiment workshop can be found in the document entitled: "Head-up Surveillance Symbology Workshop" by D. T. Wong.

the display range is highly dependent on the ownship aircraft type and its operational environment.

All of the studies reviewed above therefore suggest that range filter is one method to automatically reduce the clutter created by traffic surveillance symbology. Although this method has been suggested in the literature, definite proof of the benefit of this concept does not exist. Consequently, this research effort was initiated to look into whether the range filter could reduce clutter and simultaneously provide better traffic detection for the XVS display.

THE EXPERIMENT

Equipment

The experiment was conducted at LaRC's Visual Imaging Simulator for Transport Aircraft Systems (VISTAS-3). VISTAS-3 is a piloted fixed-base simulation facility.

There were four head-down liquid-crystal displays (LCDs) representing the Primary Flight Display (PFD), ND, Mode Control Panel (MCP), and the Fuel Systems Display (FSD) respectively. All the visual displays and input/output functions were provided by two Silicon Graphics workstations. The simulator's control laws approximated the HSCT's dynamics and engine performance during approach and departure phases. A spring-loaded sidestick controller was the primary control inceptor in this experiment. There was a red button on the sidestick which functioned as a declutter switch. When the button was pressed, all symbology (PXD and IFOV display) disappeared until the button was released.

Both the PXD and the IFOV display consisted of simulated high-resolution camera video imagery, and symbolic information was provided on the PXD using the HSR Flight Deck Minimum Symbology (FDMS) set. Horizon line and heading scale were the only symbology elements present on the IFOV display at all times.

Subjects

Three NASA LaRC in-house pilots were involved in this experiment as test subjects. They all had over 10 years of experience in flying various types of aircraft such as glass-cockpit transports and experimental aircraft with head-up displays and synthetic vision displays.

Scenarios

Each pilot flew two simulated scenarios, a departure and an arrival, under Visual Meteorological Conditions. The scenarios were medium (24,000 ft MSL) to ground level approaches and departures to NASA Wallops Airfield. Each scenario lasted approximately 9 minutes. Autopilot and autothrottle were engaged in every run. The approach scenario began from a descent at 7000-ft MSL at 250 KCAS to 1500 ft. After a turn at 1500 ft to the base leg, the aircraft initiated a deceleration to 159 KCAS. Several minutes after the deceleration, another turn was made to the final approach segment. A descent from 1500 ft to the runway threshold at 500 ft was then made to end the scenario. For the departure scenario, the aircraft began at the end of the runway at 1500-ft MSL and 159 KCAS with the landing gear retracted. Several minutes into the simulation, the aircraft began accelerating to 250 KCAS. Upon completing the acceleration, the aircraft made a 45-degree right hand turn before climbing to 7000 ft MSL to end the scenario.

There were 15 traffic aircraft in each scenario. The traffic types, performances and sizes were configured to resemble Beechcraft-200s, Boeing-737s, and HSCTs. Traffic began to appear approximately 5 minutes into each run in a clutter formation. This multi-aircraft set up was intended to allow a more effective evaluation of both the range filter and the IFOV display HUSS simultaneously. The same encounter geometries were used for the traffic in each run though the order of the aircraft's appearance varied. A plan view of traffic information was provided on the head down ND at all times. Pilots were allowed to touch the traffic symbols on the ND to display the corresponding traffic type and speed information on the ND. In addition, touching traffic symbols on the ND displayed the head-up traffic symbol on the XVS, regardless of the current traffic category and the size of the range filter.

Detecting and assessing potential airborne traffic hazards while managing flight path and maintaining overall situation awareness along the flight path were the pilots' main tasks. Besides the main tasks, each pilot was also required to carry out a secondary fuel-monitoring task to increase workload. His job was to ensure the amount of fuel in each tank was within 2000 pounds of each other by manipulating the controls on the FSD. A simulated leak rate of 1000 pounds per minute was introduced to either the left or the right tank. This leak forced the pilot to perform a fuel transfer task. The fuel imbalance did not actually affect the ownship's performance or flying qualities. Upon completing all the runs, each pilot was asked to complete a questionnaire. In essence, the questionnaire asked the pilots to rate the effectiveness of various HUSS symbology combinations and to provide their opinions on these concepts.

Experiment Design

In each run, the pilot was exposed to either an arrival or a departure scenario to simulate traffic surveillance events against backgrounds of ground or sky textures in different speed regimes. A scale that rates the subjective effectiveness of the various XVS HUSS concepts was used as a measure of the dependent variable.

For the no-range-filter and no-HUSS-on-IFOV-display combination, the resulting HUSS configuration provided only TA and RA categories of traffic information. This combination represented the current HUSS definition in which only traffic considered threatening (generated TA or RA alerts) was displayed on the PXD. There was no traffic information at all on the IFOV display. The no-range-filter and with-HUSS-on-IFOV-display combination was the configuration in which both the PXD and the IFOV display had TA and RA categories of traffic information. However, proximate traffic information was not available to either display unless the pilot pressed individual traffic symbols on the ND. The with-range-filter and no-HUSS-on-IFOV-display combination represented the condition that only the PXD had a 7-nmi range filter for displaying proximate, TA, and RA categories of traffic information. There was no traffic information at all on the IFOV display. Finally, the with-range-filter and with-HUSS-on-IFOV-display combination created the configuration in which the range filter was applied to both the PXD and the IFOV display. Traffic symbols of all categories (proximate traffic, TA, and RA) were therefore available on both displays.

Hypothesis

The hypotheses tested in this experiment were the following: (1) adding a range filter to both XVS displays would enhance the pilot's overall effectiveness in traffic detection and avoidance; (2) adding HUSS to the IFOV display would also enhance the pilot's effectiveness in traffic detection and avoidance for traffic within the IFOV; and (3) the XVS concept would be the most effective in traffic detection and avoidance when the range filter is combined with the HUSS on the IFOV display.

RESULTS

Data Summary

After the experiment, a numerical scale with values from 1 to 9 was assigned to the answers of the questionnaire given to each pilot. Values of 1 meant the pilot marked either "strongly disagree" or "highly ineffective" on the answers. Values of 9 meant the pilot put down either "strongly agree" or "highly effective". Tables 1-4 contain brief descriptions of each question in sections I to IV of the questionnaire and the corresponding ratings the pilots provided. Table 5 and 6 summarize the results of section IV

Section I Results: HUSS on the IFOV Display

All pilots rated from "Agree" to "Strongly Agree" on questions concerning the traffic detection ability with the HUSS on the IFOV display. The pilots either "Disagreed" or "Strongly Disagreed" that having HUSS on the IFOV display created too much clutter. In general, the pilots thought that having HUSS on the IFOV display greatly enhanced their situational awareness and reduced their workload. It also reduced the need to hunt in order to distinguish a particular piece of traffic, especially when the pilot needed to make a turn towards the direction covered by the IFOV display. Two pilots thought that the same rules and properties used for HUSS on the PXD should apply to the HUSS on the IFOV display.

Table 1. Description of Questionnaire Inquiries and the Pilot Ratings for HUSS on the IFOV Display

Question Number	Question Descriptions (HUSS on IFOV)	Pilot Ratings		
		S1	S2	S3
I.1	Increases traffic detection ability	9	9	9
I.2	Increases threatening traffic detection ability	7	8	9
I.3	Created too much clutter	3	2	3
I.4	Reduces workload	7	7	9
I.5	Increases awareness of nearby traffic	9	8	8

Section II Results: Range Filter on both XVS Displays (PXD and IFOV display)

All pilots either "Agreed" or "Strongly Agreed" that having a range filter on both XVS displays increased their ability to detect traffic and at the same time reduced their workload. Two pilots "Disagreed" that the range filter created too much clutter. One of the pilots was "Neutral" on this issue.

Pilots generally thought the range filter reduced workload in a multi-aircraft environment by automatically displaying proximate traffic. The pilots also felt that adding the range filter reduced head down time because it greatly reduced the need to manually select aircraft on the ND, one-at-a-time, to display the corresponding HUSS symbol on the head-up XVS displays.

Table 2. Descriptions of Questionnaire Inquiries and the Pilot Ratings for Range Filter on the PXD & the IFOV Display

Question Number	Question Descriptions (Range Filter on PXD & IFOV)	Pilot Ratings		
		S1	S2	S3
II.1	Increases detectability of traffic nearby	8	8	9
II.2	Increases ability to assess potentially threatening traffic	7	7	7
II.3	Created too much clutter	3	5	3
II.4	Reduces workload	8	7	9
II.5	Increases awareness of nearby traffic	9	8	9

Section III Results: Range Filter on the PXD & the IFOV Display and HUSS on the IFOV Display

When the pilots were asked whether both the display options (i.e., adding a range filter to both XVS displays and HUSS on IFOV display) should be added to the current display concept, they either put down "Agree" or "Strongly Agree".

Table 3. Description of Questionnaire Inquiries and the Pilot Ratings for Range Filter on the PXD & the IFOV Display and HUSS on the IFOV Display

Question Number	Question Descriptions (Range Filter on PXD & IFOV and HUSS on IFOV)	Pilot Ratings		
		S1	S2	S3
III.1	Both should be applied to approach and departure	9	8	7
III.2	TA & RA should be transferred automatically to both XVS displays	9	8	9

Section IV Results: Comparisons of the Four Display Configurations

The remaining subjective rating questions were related to the effectiveness of different combinations of the new display concepts. Table 5 reveals that the display configuration with the range filter and the HUSS on the IFOV display was the most effective concept among the four combinations examined.

A two-way ANOVA procedure was applied to find out if there were significant differences among the treatment combinations. The ANOVA result is presented in Table 6, which shows that both the range filter and the HUSS on the IFOV display were significant treatment factors. The results also show that there is very little interaction between the two factors. However, the low value of its observed power implies that only large interaction effects would have been detectable.

Table 4. Descriptions of Questionnaire Inquires and Pilot Ratings of Section IV

Question Number	Question Descriptions	Pilot Ratings		
		S1	S2	S3
IV.1	Effectiveness of w/o Range Filter and w/o HUSS on IFOV	3	5	3
IV.2	Effectiveness of w/o Range Filter and w HUSS on IFOV	5	7	4
IV.3	Effectiveness of w/ Range Filter and w/o HUSS on IFOV	6	6	5
IV.4	Effectiveness of w/ Range Filter and w HUSS on IFOV	8	8	9

Table 5. Means and Standard Deviations of the Results of Section IV

	W/O Range Filter		W/ Range Filter	
	W/O HUSS on IFOV	W/ HUSS on IFOV	W/O HUSS on IFOV	W/ HUSS on IFOV
Mean	3.67	5.33	5.67	8.33
Std Deviation	1.1547	1.5275	0.5774	0.5774

Table 6. ANOVA Summary of Section IV

Error Source	DOF	Mean Sqr.	F	Signifi-cance (α• = 0.05)	Observed Power
X	1	18.75	17.31	0.003	0.952
Y	1	14.08	13.00	0.007	0.883
X * Y	1	0.75	0.69	0.430	0.114
Error	8	1.08			
Total	12				

Where:
X = Range Filter
Y = HUSS on IFOV Display

Additional Comments

The pilots also provided additional comments that are valuable for improving the existing XVS display concept, or any future surveillance display concepts such as the displays for the upcoming Synthetic Vision System Project for NASA's Aviation Safety Program.

In this HUSS concept, the proximate traffic symbols being selected from the ND to appear on the XVS displays are not distinguishable from any other same category traffic once the traffic enters the range filter's boundary. One pilot thought it would be desirable to have a scheme to highlight the selected traffic symbol on the head-up displays. This would be very useful when the Air Traffic Control gives a clearance in terms of following another aircraft.

There was also a concern that the TA symbol of the HUSS was sometimes confused with the glideslope and localizer pointers on the PXD display.

A decluttering capability was thought to be "a must". The symbology was believed to be very helpful for traffic detection but slightly less so for threat determination. This is because the symbology helped with the bearing rate, but it was quicker at close ranges to determine the range rate by actually viewing the traffic. Doing so required decluttering the head-up display momentarily. One pilot recommended a two-position declutter switch. The first position would declutter the traffic symbols on the XVS and the second position would declutter all symbology including flight symbology. This setup would be more important while flying the aircraft manually. Another declutter idea suggested was a pilot-variable range filter to declutter all symbols except any TA and RA category traffic. The range filter should have the ability to allow the pilot to select the range based on traffic conditions and phase of flight.

CONCLUSIONS

The answers to the questionnaires indicated that the pilots gave favorable ratings when the range filter was applied to the XVS display concept. Furthermore, the HUSS should be applied to both the IFOV display and the PXD for the XVS surveillance display concept to be effective. The pilots' opinions were further confirmed by quantitatively analyzing some of the questionnaires' result with an ANOVA procedure. The analysis revealed that the treatment condition with both factors present (HUSS on IFOV and range filter on) was not only the most favorable but also statistically significant.

The subjective data gathered in this experiment imply that applying HUSS onto the IFOV display and having a range filter on both the PXD and the IFOV display enhance the effectiveness of the XVS surveillance display concept. Pilots' thought this configuration had the least head down time and the lowest mental workload. Combining both features gave the best traffic detection, the earliest threat recognition, and the best situation awareness. This configuration also enabled the pilots to create a better strategy for evasive action when it became necessary. The pilots also thought that the HUSS helped direct the pilot's attention to the IFOV area if there was traffic there, whether threatening or not. With the range filter, it was no longer necessary to spend extra time searching for the traffic and mentally transferring their bearing angles from the navigation display, one at a time, to the IFOV display. Therefore, the pilots had more time for other tasks.

The results of this study confirmed the hypotheses tested which were that (1) adding a range filter to both XVS displays would enhance the pilot's overall effectiveness in traffic detection and avoidance; (2) adding HUSS to the IFOV display would also enhance the pilot's effectiveness in traffic detection and avoidance for traffic within the IFOV; and (3) the XVS concept would be the most effective for traffic detection and avoidance when the range filter on both displays is combined with the HUSS on the IFOV display.

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